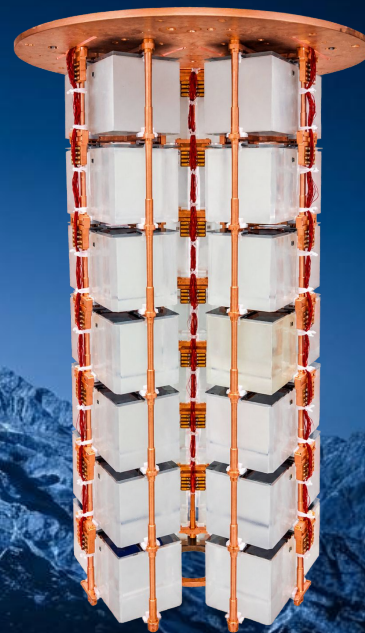


The CROSS Demonstrator: Structure, Low-Background Techniques, and Physics Reach

Roberto Serino on behalf of the CROSS
collaboration

IJCLab - CNRS - Université Paris Saclay

Low Radioactivity Techniques
24th September 2026 - York, United Kingdom



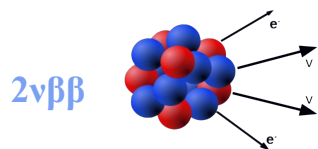
LOW
RADIOACTIVITY
TECHNIQUES

2026
WORKSHOP X

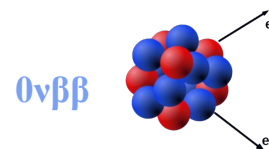
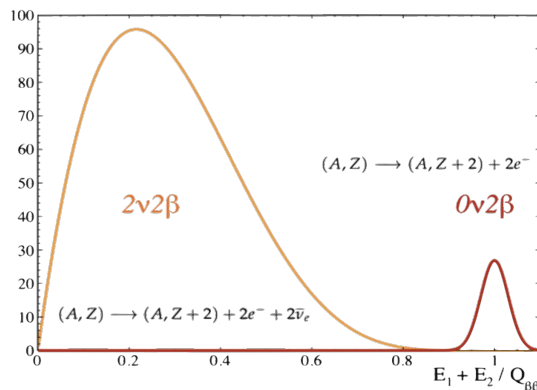
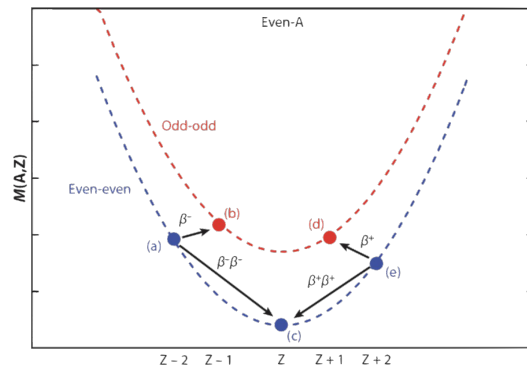


Double beta decay

Double beta decay: rare second-order weak process in which a nucleus undergoes two **simultaneous** beta decays



- Allowed by the Standard Model for even-even nuclei ($\Delta L = 0$)
- First direct **observation** in 1987 in ^{82}Se
- Half life $T_{1/2} \sim 10^{18} - 10^{24}$ yr
- Signature: **continuous spectrum** from 0 up to the $Q_{\beta\beta}$

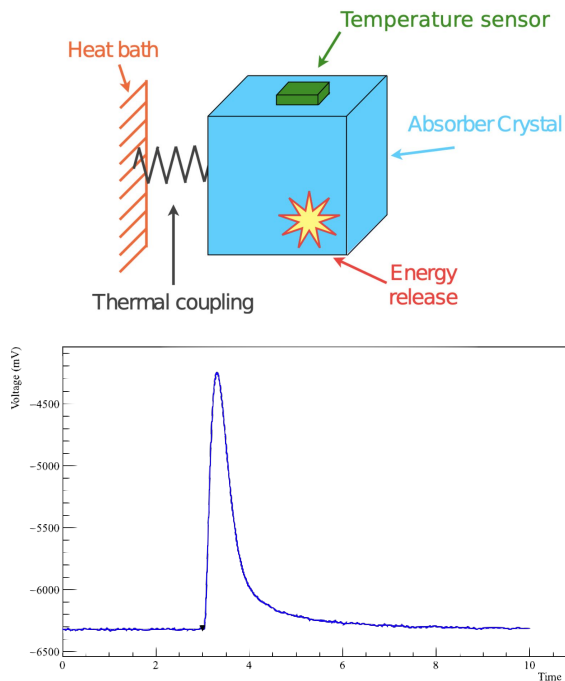


- **Violates** the lepton number symmetry ($\Delta L = 2$)
- **No experimental evidence** up to now
- Half life $T_{1/2} > 10^{24} - 10^{26}$ yr
- Signature: **peak at the $Q_{\beta\beta}$**
- Could play an important role in the **matter-antimatter asymmetry**

Cryogenic Calorimeters

The energy deposited by particles is converted into **phonons**

→ Through a **sensor** (Ge-thermistor) the heating of the absorber is measured



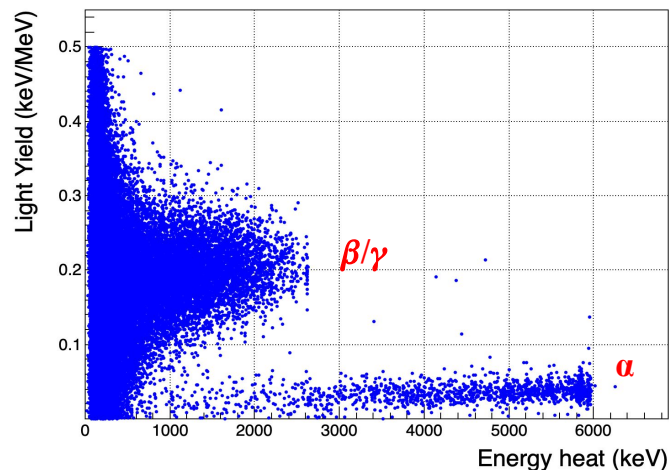
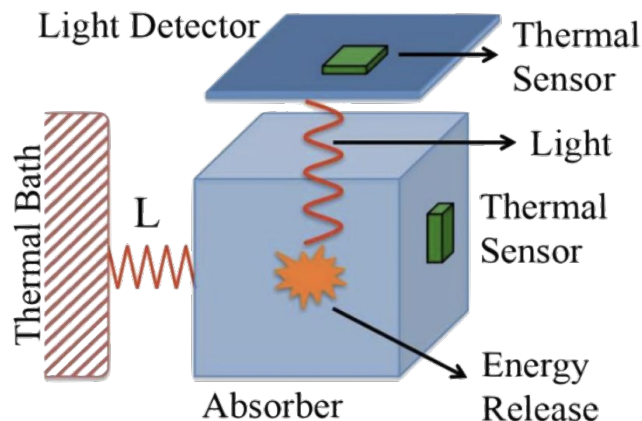
- The absorber is operated at approximately **10 mK**
- **Slow** signal response (timescale of ~ 1 s)
- **Excellent** energy resolution ($\text{FWHM} \approx 0.1\%$) at the $Q_{\beta\beta}$
- **$\beta\beta$ source** is **embedded** within the detector (high detection efficiency)
- Wide choice of absorber **materials**, allowing the use of different **$\beta\beta$ isotopes**
- **Scalable** technology (ton-scale experiment)

What to improve for a next generation experiment?

α 's from **surface radioactivity dominate** background in the Region of Interest (ROI) → **α rejection is pivotal**

↳ **Scintillating calorimeters** enable α -event rejection due to their **lower light yield** compared to β/γ

→ To enhance **SNR** and **discrimination** the **Neganov-Trofimov-Luke** (NTL) effect is exploited



$$LY = \frac{E_{light}}{E_{heat}}$$

Neganov-Trofimov-Luke (NTL) effect

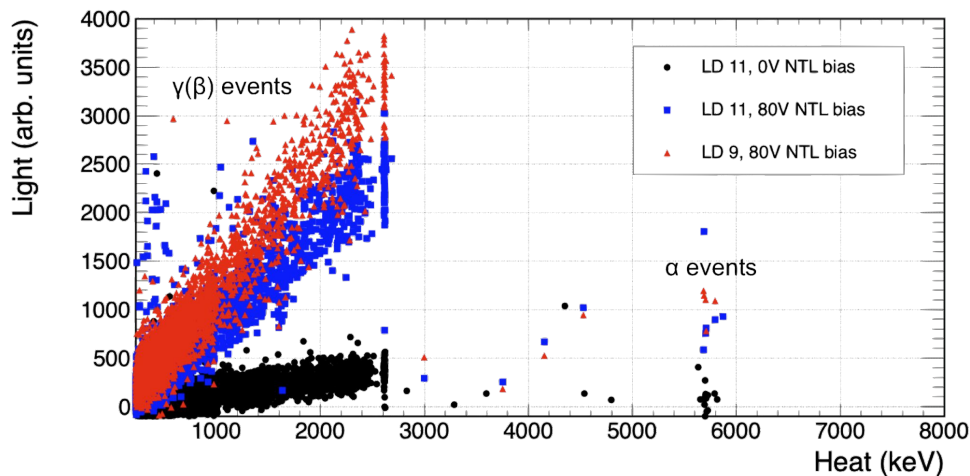
Light detector performance can be enhanced by the **Neganov-Trofimov-Luke effect**: $E_{tot} = E_0 \left(1 + \frac{q \cdot V_{el} \cdot \eta}{\epsilon} \right)$

→ Electric field generated applying Voltage (V_{el}) on the **electrodes** deposited on the LD

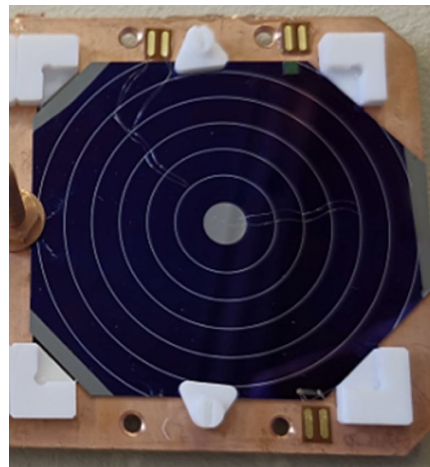
→ Impinging particle generates electron-hole pairs that **drift** through the field $\longrightarrow$

→ **SNR** can be increased by an order of magnitude

Extra heat is produced
thanks to the drift
(increased amplitude)



[JINST 21 P01035 (2026)]



Higher SNR improves
pile-up rejection.

Crucial for CUPID:
Mitigation of background
induced by **random**
coincidences of ordinary
 $2\nu\beta\beta$ events

The CROSS experiment

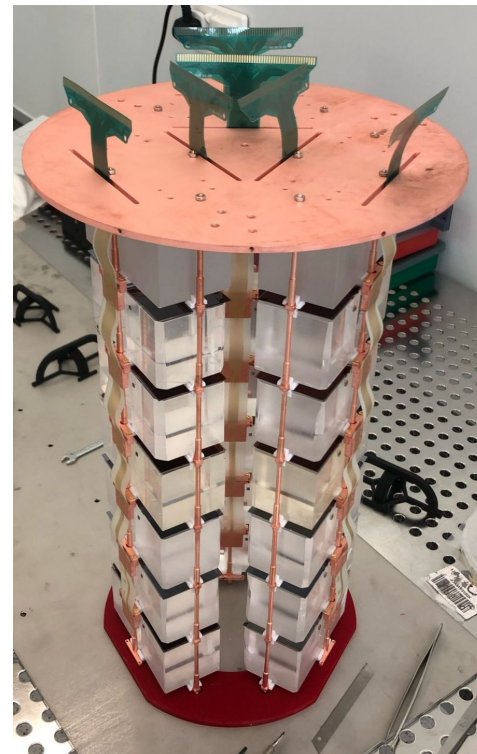
CROSS (**C**ryogenic **R**are-event **O**bservatory with **S**urface **S**ensitivity) is hosted in the Canfranc Underground Laboratory (LSC), in Spain at a depth of ~ 2400 m.w.e. CROSS is taking data since December 2025.

[\[arXiv 2607.26732 \(2026\)\]](#)

3 towers with 7 floors each

- Each floor has 2 crystals + 2 LDs
- Top floors consists of 6 $^{130}\text{TeO}_2$ crystals, that will work also as shielding to others crystals due to higher density (mass of ^{130}Te : ~ 2.4 kg) [\[JINST 19 \(2024\) P09013\]](#)
- $36 \text{ Li}_2\text{MoO}_4$: 32 enriched, 2 depleted and 2 with natural isotopic abundance (mass of ^{100}Mo : ~ 4.9 kg)

Facility equipped with **lead** shielding, **anti-radon** system (~ 1 mBq/m³) and **muon veto** [\[JINST 18 \(2023\) P12004\]](#)



CROSS: what's new

CROSS exploited key technologies relevant to next generation neutrinoless double-beta decay experiments:

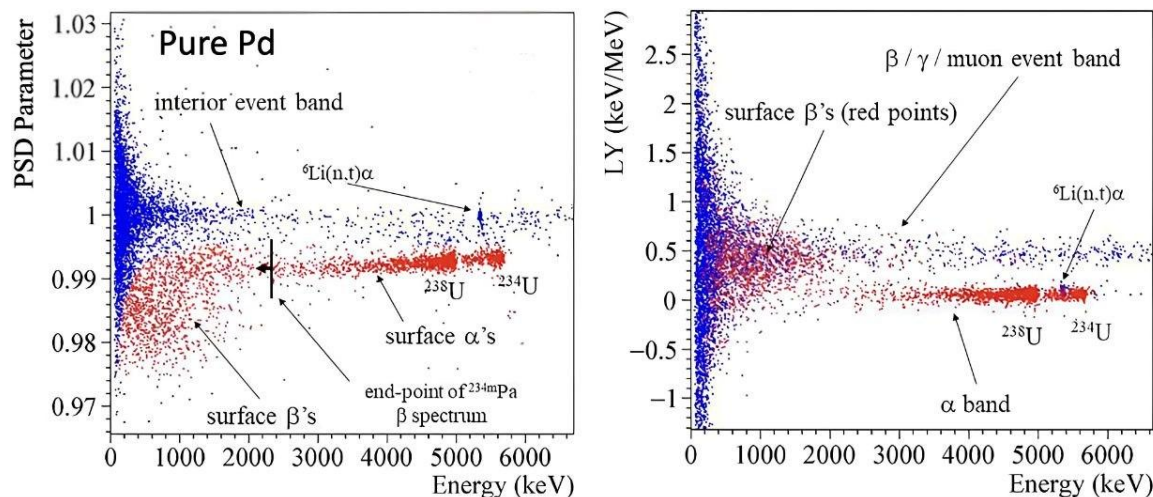
1. **Surface-coated** crystals for bulk/surface event discrimination (α and β)
2. Optimization of Neganov–Trofimov–Luke (**NTL**) light-detector technology
3. Deployment of **Silicon**-wafer NTL light detectors in a **medium-scale** detector array
4. Full $\alpha/\beta(\gamma)$ separation was achieved in an **open structure** without the use of **reflective films**
5. New **low-mass** mechanical structures minimizing **passive material** near the detectors
6. Development of the purification and crystallization process for **enriched** $^{130}\text{TeO}_2$ crystals

CROSS: Surface Sensitivity

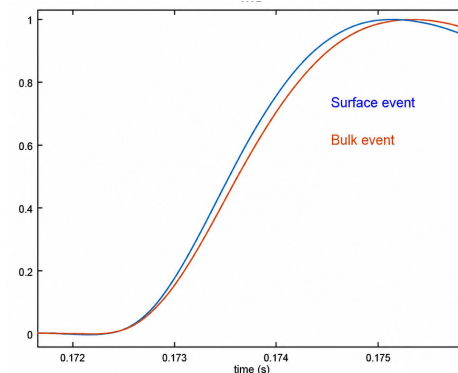
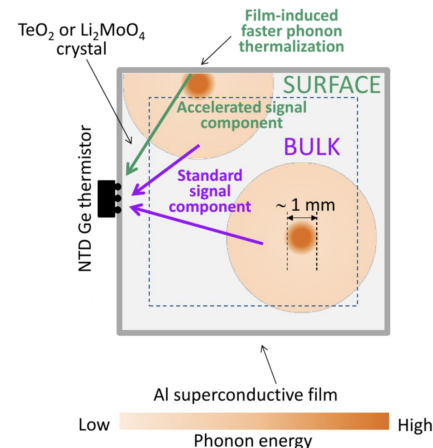
Metal films act as **pulse-shape modifiers** for charged particles depositing energy near the film surface → **Bulk vs Surface event discrimination**

After long R&D with $2 \times 2 \times 1 \text{ cm}^3$ → **Al-Pd bi-layer** was selected

[\[APL 118 184105 \(2021\)\]](#)



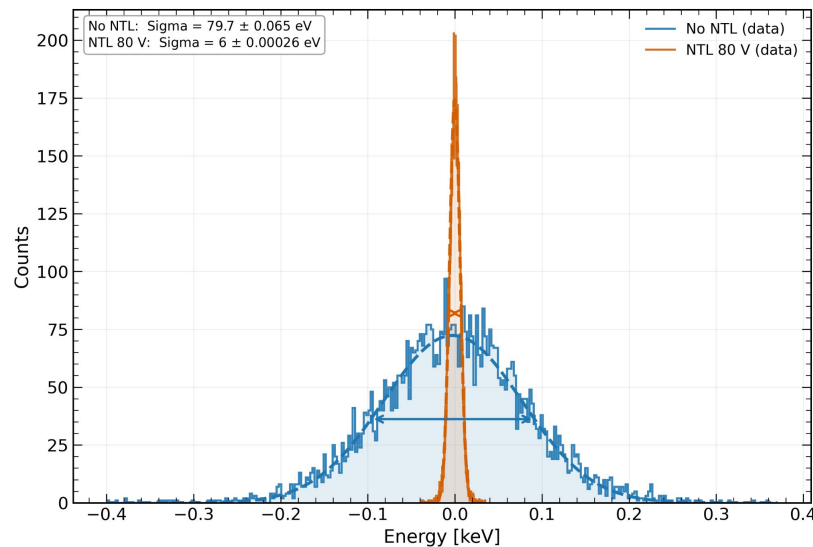
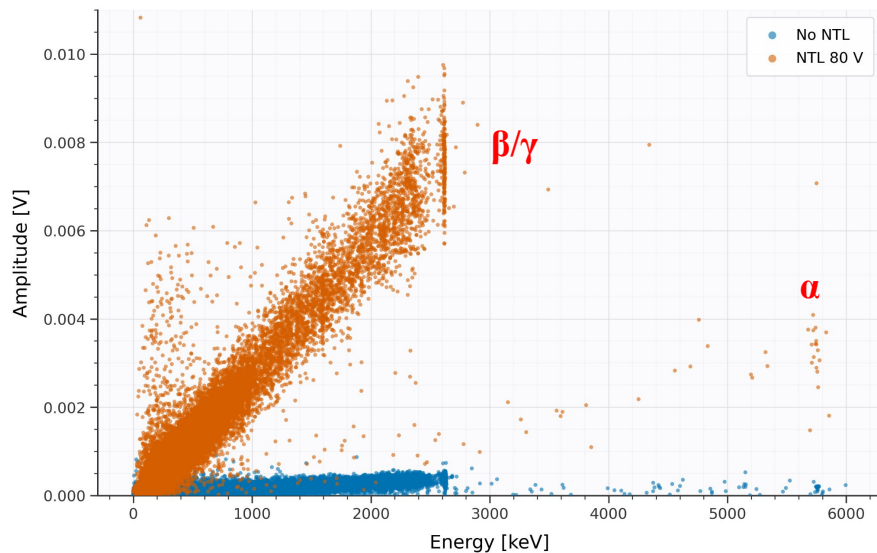
Unfortunately, this technology is **not mature enough** to be scaled to large CROSS size crystals ($4.5 \times 4.5 \times 4.5 \text{ cm}^3$)



NTL effect allows us to achieve:

- Very good discrimination power (~ 5)
- Low Baseline Noise (FWHM ~ 10 eV) on Light Detectors

α background reduction > 99.9 %



CROSS: Background model

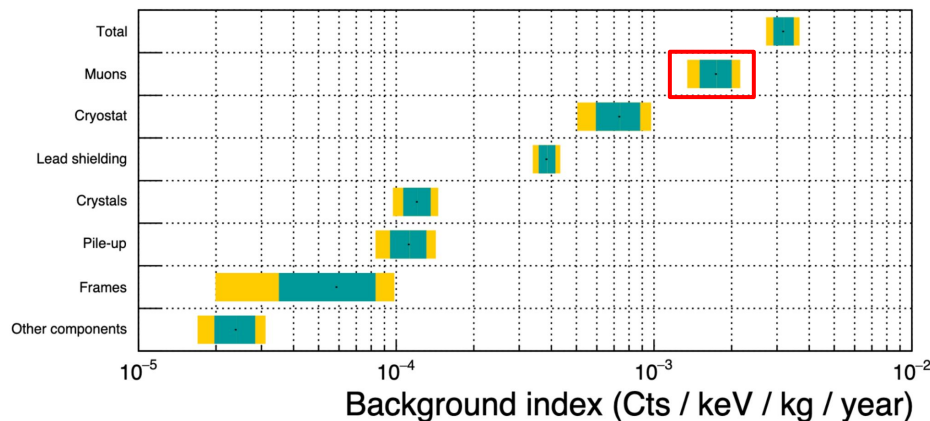
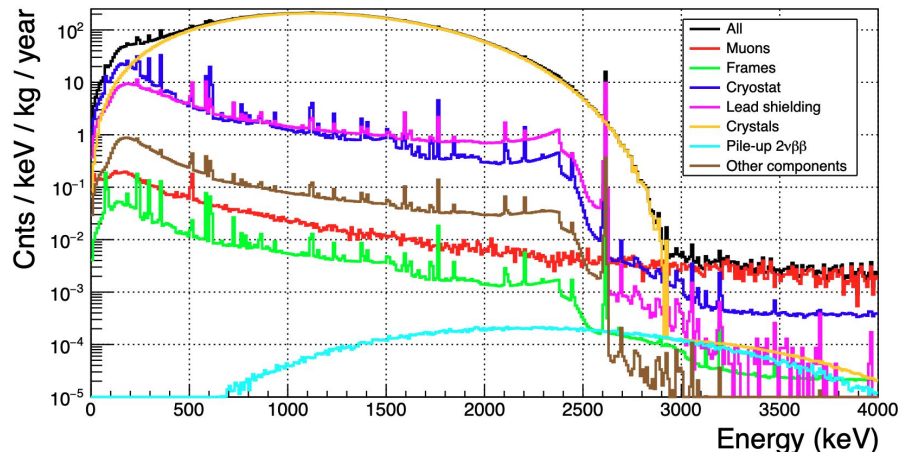
[EPJC 83 675 (2023)]

- Assuming the same radiopurity for crystals, copper frames and kapton pads as in CUPID-Mo experiment
- Radioactive contaminations of close components were screened using HPGe γ spectroscopy
- 100 keV-wide region centered at $Q_{\beta\beta}$ (3034 keV)

The predicted **Background Index** in ROI background is $3.2(5) \times 10^{-3}$ cts/keV/kg/yr [arXiv 2607.26732 (2026)]

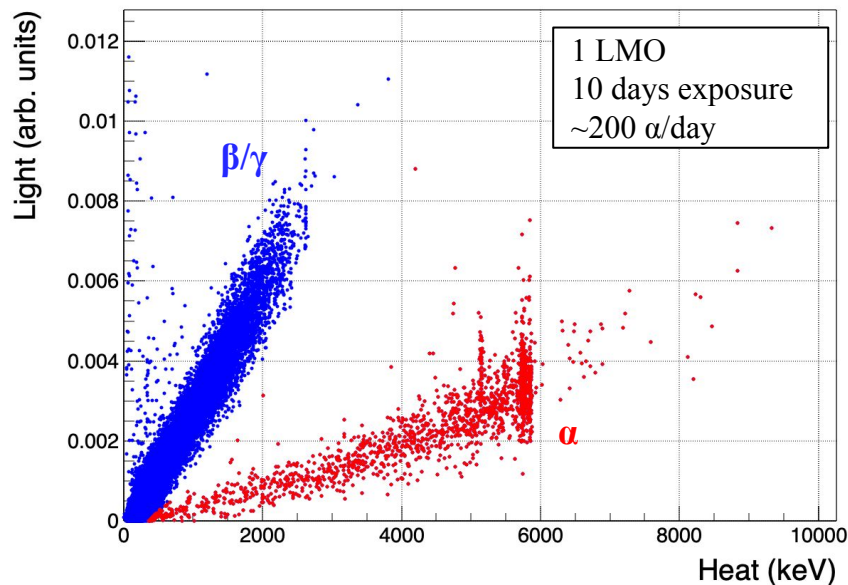
- Biggest contribution is given by muons: **Muon veto** is necessary [JINST 21 P05007 (2026)]

Would allow the **best sensitivity** to $0\nu\beta\beta$ decay in ^{100}Mo



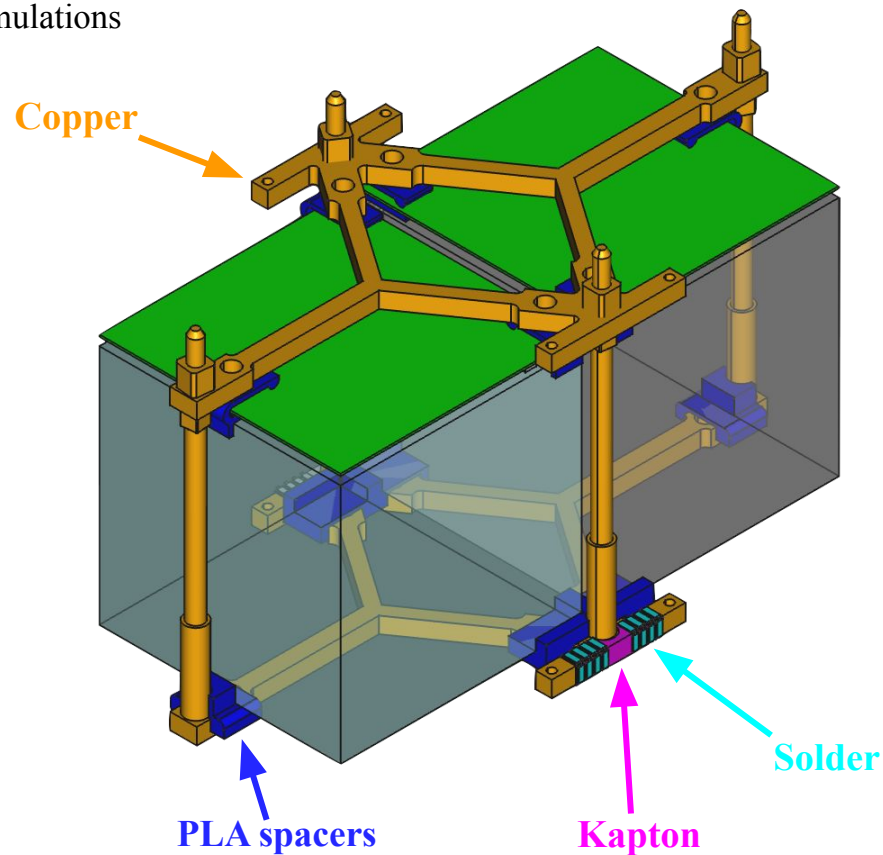
CROSS: Background results

CROSS data presented a **higher background** than expected from simulations



A strong α contamination is present **close to the detectors**

→ Although α events can in principle be **rejected**, the **high α rate** complicates the analysis and makes it difficult to understand the **residual background** in the ROI.

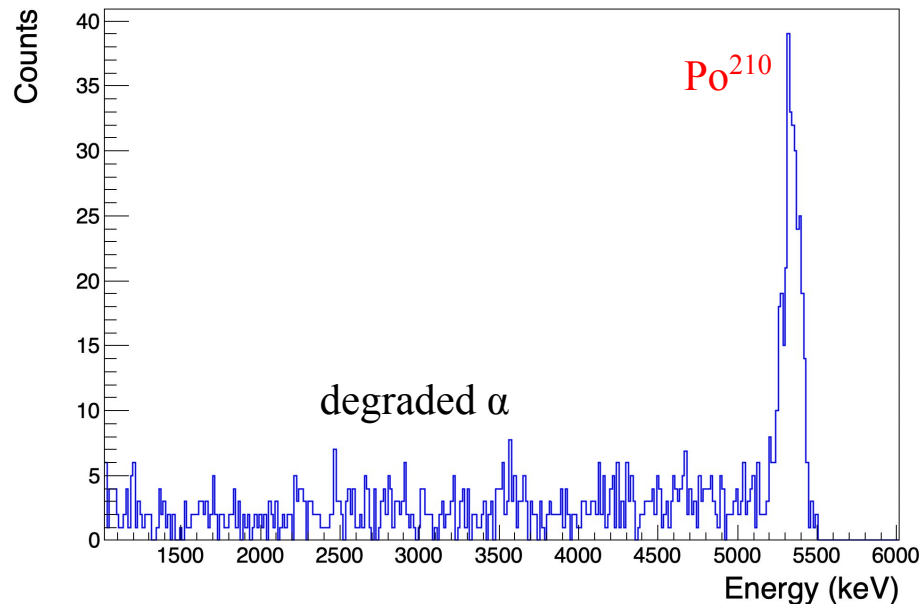
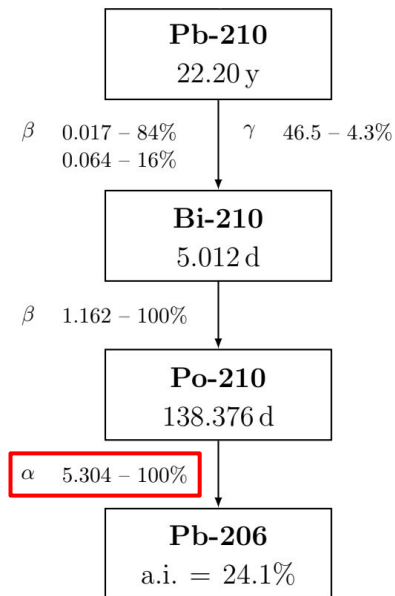


CROSS: α contamination

Several measurement with different materials have been conducted at IJCLab using a **Passivated Implanted Planar Silicon** (PIPS) detector in order to understand the origin of the contamination

The contamination seems to be due to the **solder** ($\text{Sn}_{96.5}\text{Ag}_3\text{Cu}_{0.5}$) used for read out the detector

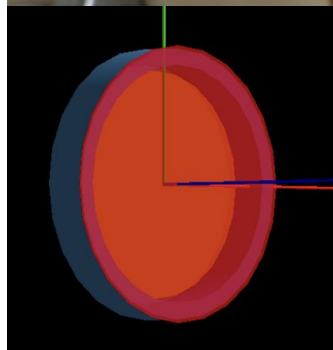
^{210}Pb contamination present in the solder



CROSS: α contamination

Monte Carlo simulations have been performed to fit the **profile of the contamination**

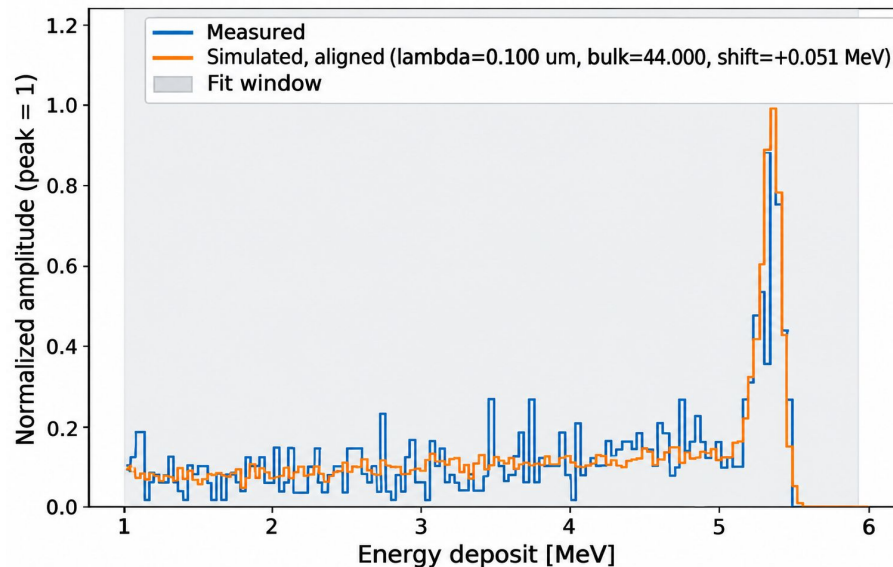
The profile fit allows us to account for the contamination in the CROSS geometry → **MC simulation ongoing**



Detector

Housing

Soldering
disk



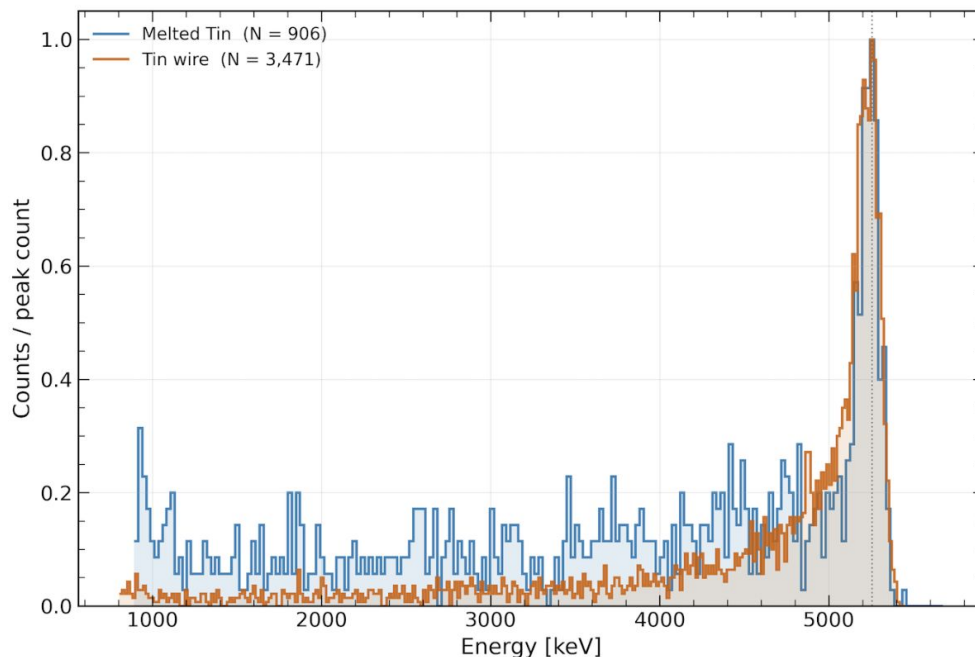
The profile utilized is: $\text{PDF}(x) = L(e^{-\lambda x} + B)$

$L = 20 \text{ um}$ (α range in solder)

$\lambda \rightarrow 0$ Surface Peaked

CROSS: α contamination

A measurement of the solder was performed **before melting**



Fit results:

Melted Solder: $\lambda = 0.1 \text{ um}$

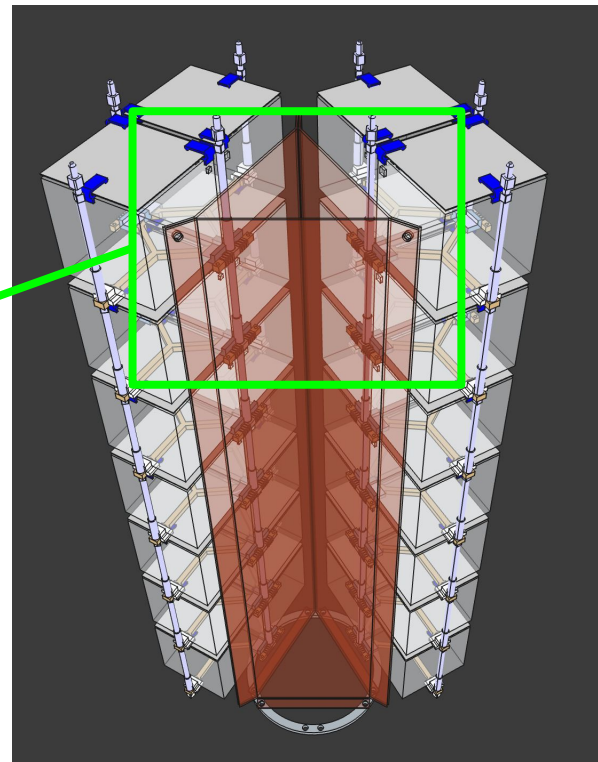
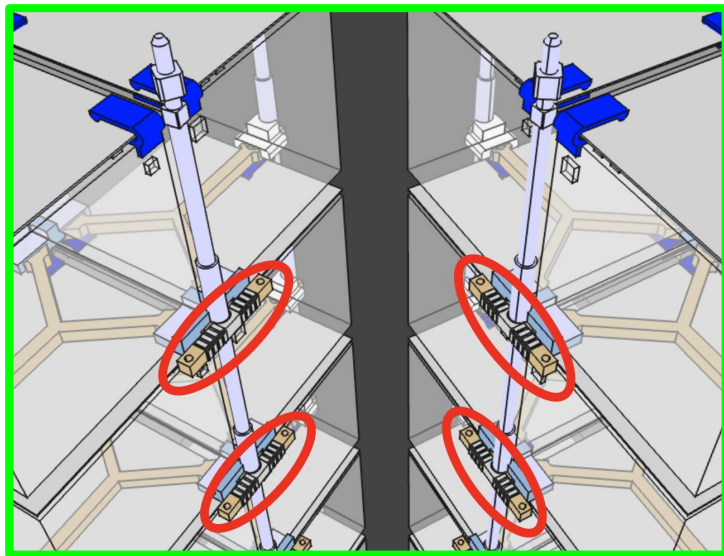
Solder Wire: $\lambda = 0.55 \text{ um}$

Thermal treatment can promote the migration of ^{210}Po toward the surface.

^{210}Po migration toward the surface after thermal treatment has been reported in literature
[\[IMAPS JMEP 10, 73-79 \(2013\)\]](#)

CROSS: α contamination

A major intervention to the setup is planned in **fall 2026** to shield the α 's
(Solder deposited on the copper pieces circle in **red**)



A **triangular prism** will be inserted in between the three towers

STAY TUNED!

Summary

- CROSS could achieve the **best sensitivity** to $0\nu\beta\beta$ decay in ^{100}Mo
- Silicon could provide a **lower-cost alternative** to germanium
- CROSS is demonstrating the NTL technology over an **extended period of time**
- Several **Background reduction** techniques have been exploited:

Active background reduction:

- Surface-Sensitivity detectors
- Muon Veto system
- Light Detector (light-based discrimination)
- NTL technology (pile-up rejection)

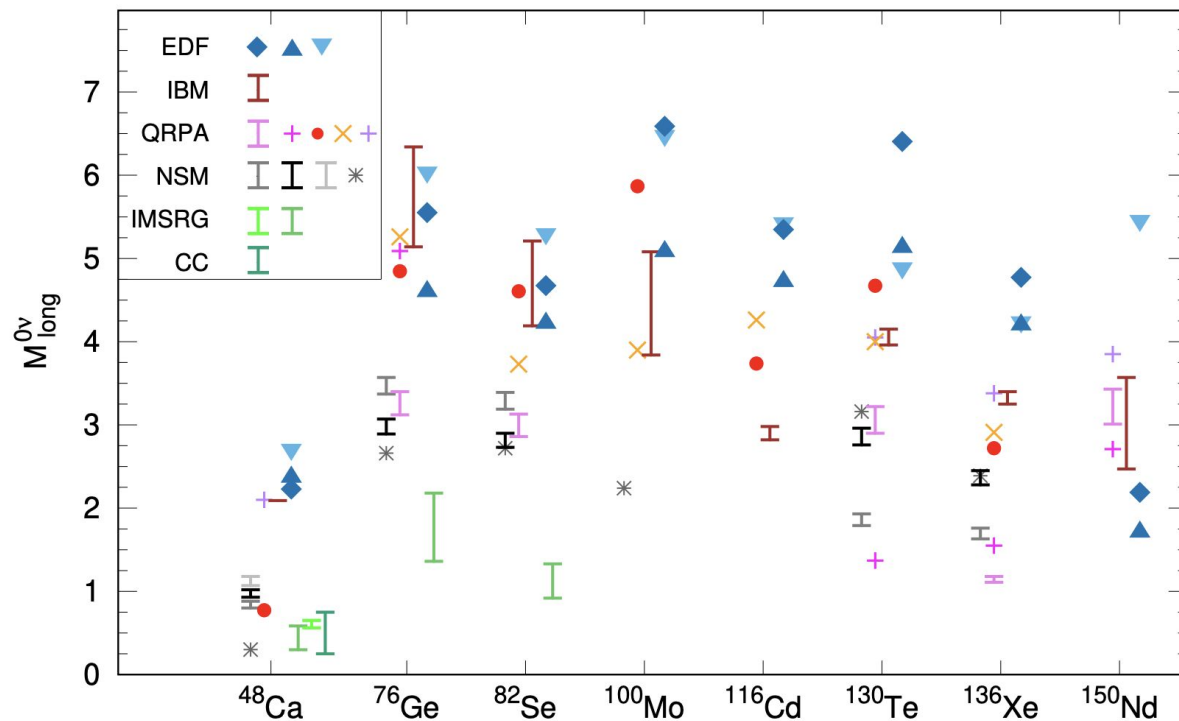
Passive background reduction:

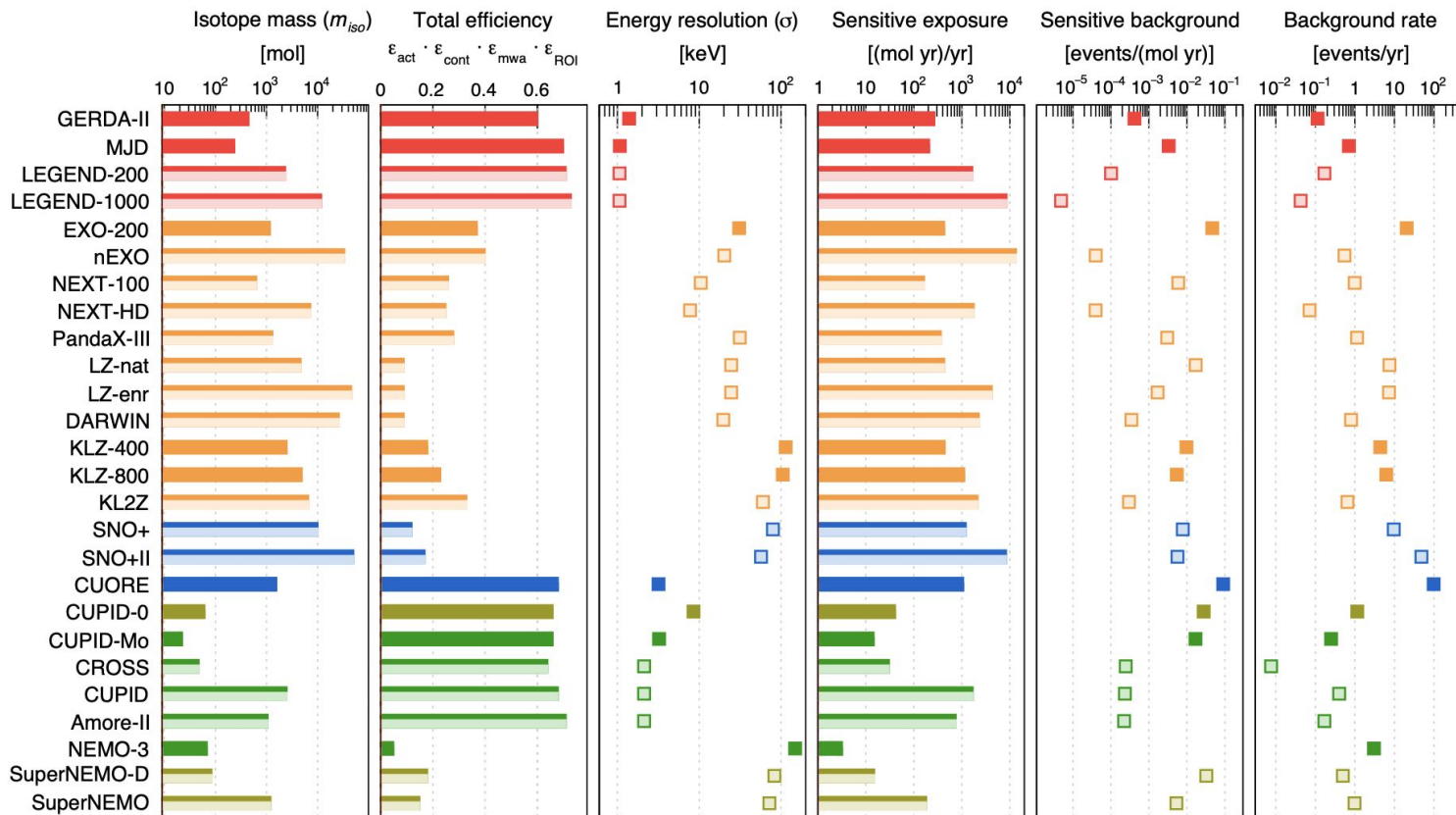
- Lead Shielding (internal and external)
- Radon suppression system
- Deep-underground operation
- Low-mass mechanical structure

Thank you on the behalf of the
CROSS collaboration

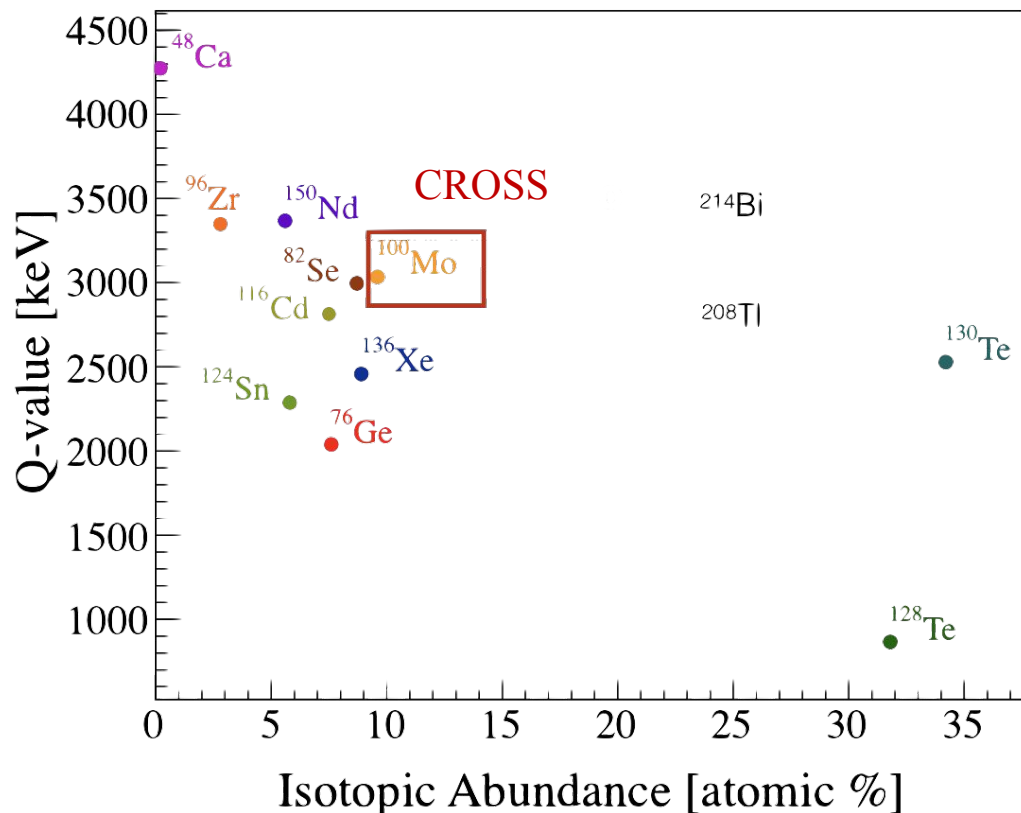
Backup

[Rev. Mod. Phys. 95 025002 (2023)]





Backup

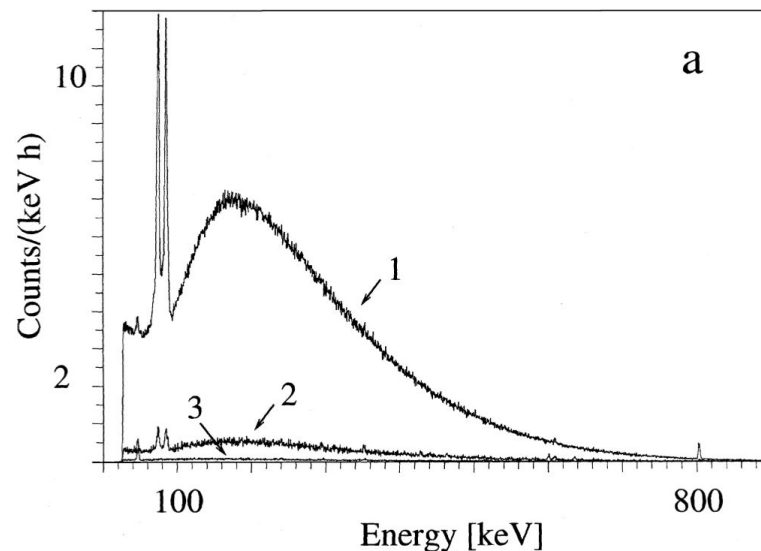
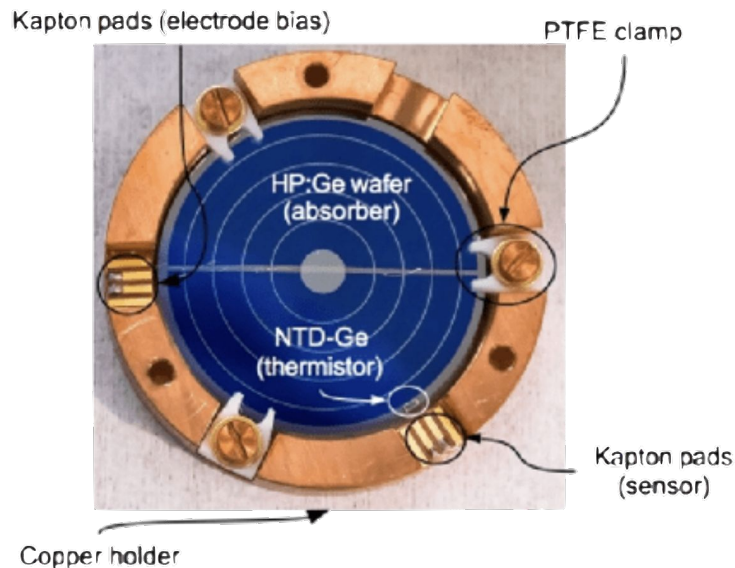


$$\frac{1}{T_{1/2}^{0\nu\beta\beta}} \sim g_A^4 \cdot G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

Effective Majorana mass:

$$\langle m_{\beta\beta} \rangle = \left| \sum_{i=1,2,3} U_{e,i}^2 m_i \right|$$

Backup



[NIMB 142 163-172 (1998)]

Spectra in the region to 900 keV recorded with shields made with various types of lead:

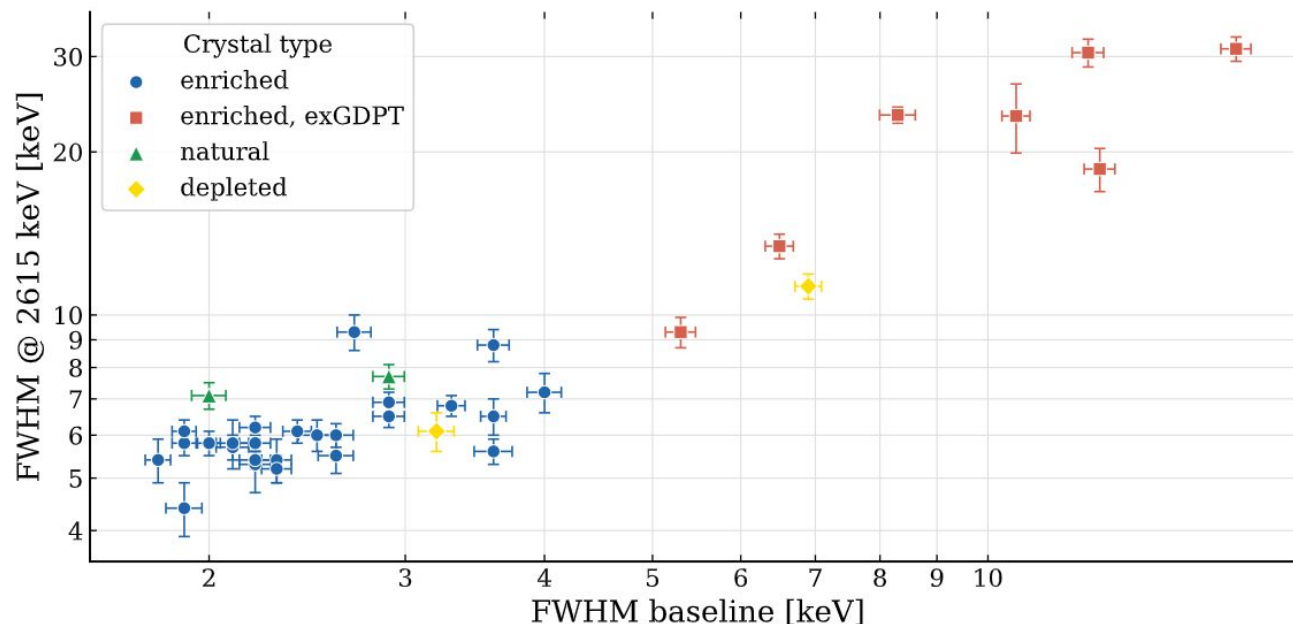
1. common modern lead;
2. modern lead with a certified content of less than 20 Bq/kg of ^{210}Pb
- 3: roman lead

Backup

The average FWHM @ 2615 keV is ~ 6 keV (0.2 %)

Some crystals (exGDPT) have degraded performance because they have been exposed to humidity

→ Li_2MoO_4 is **hygroscopic**

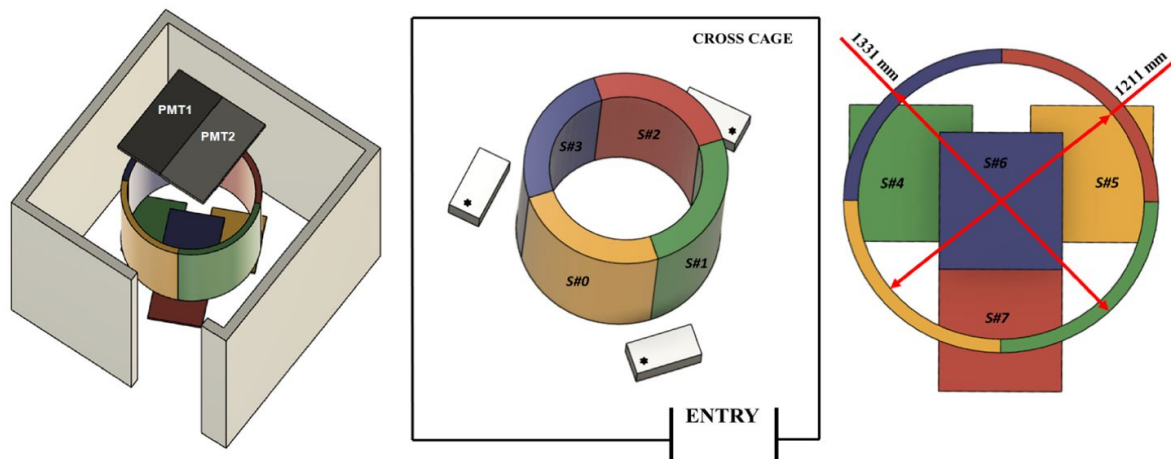


Backup

A muon veto system is required due to the residual cosmic muon flux ($\sim 20 \mu/\text{m}^2/\text{h}$), which dominates the background in the ROI.

The system consists of lateral, top, and bottom sectors. The thresholds are optimized according to Monte Carlo simulations.

Despite a high dead time ($\sim 20\%$), the veto is essential to reduce the background to $\sim 2 \times 10^{-3}$ c/ky.



[\[ArXiv 2510.27406 \(2025\)\]](#)

Extruded scintillators
Wavelength-shifter fibers SiPMs

174 channels grouped in 9 sectors

Rejection of events in coincidence
between one veto sector and
detectors

Total veto rate: ~ 95 Hz

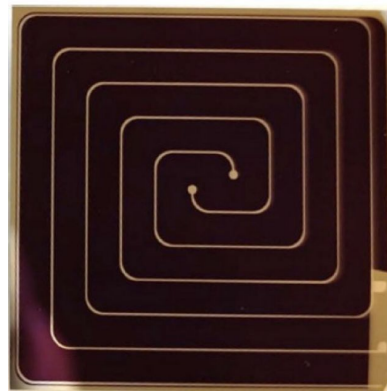
Backup

Silicon wafers may provide a **more practical solution** for a large-scale experiment, as they are significantly less expensive than germanium detectors.

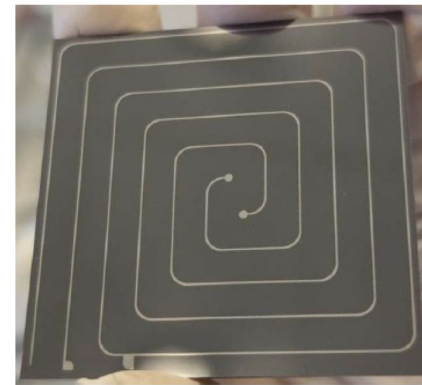
→ Si LDs are ~3 times cheaper than Ge LDs

The CROSS data will allow us to evaluate:

- NTL amplification performance and **reproducibility**
- **Bolometric** performance of Si LDs
- **Light** collection **efficiency** in Si compared to Ge
- The minimum achievable **rise time**



Germanium



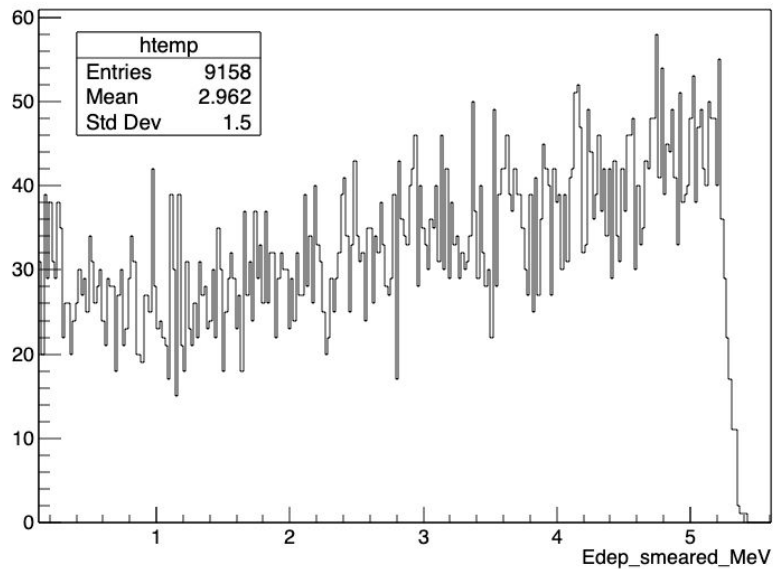
Silicon

In addition, the availability of high-purity germanium has become **increasingly limited** in recent years, making large-scale production more challenging and expensive.

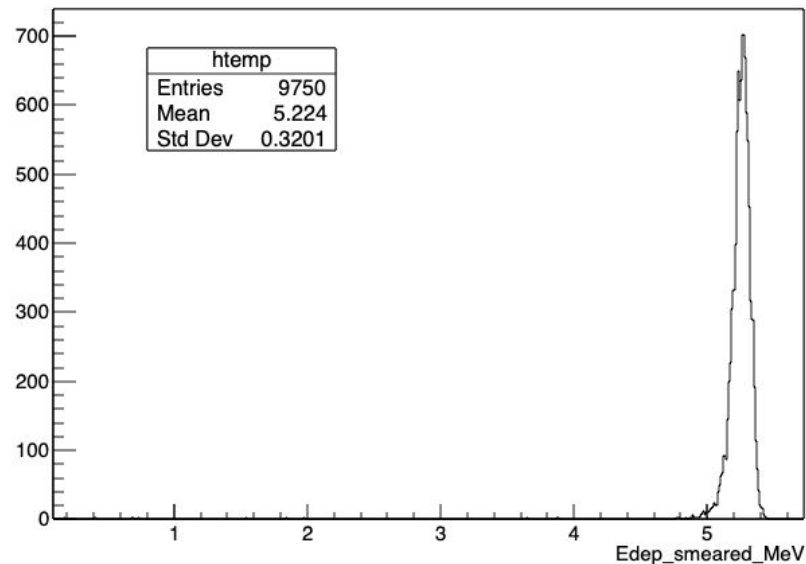
Backup

Monte Carlo simulations ^{210}Pb contamination

Pure bulk



Pure surface



Backup

Material	^{226}Ra ($\mu\text{Bq/kg}$)	^{228}Th ($\mu\text{Bq/kg}$)
Copper screens	$0.6(1) \times 10^3$	$0.3(1) \times 10^3$
Electronic pins	$1.33(4) \times 10^6$	$2.39(3) \times 10^6$
Crystals (bulk)	0.39(6)	0.57(7)
Copper frames	25(15)	33(16)
Lead shielding	< 120	< 460
Fiberglass bars	$3.4(4) \times 10^3$	$1.41(5) \times 10^3$
Kapton pads	$17(7) \times 10^3$	$67(31) \times 10^3$

